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Summary and Conclusions from the Neutrino Factory and Beta Beams Group, APS Multi-Divisional Study of the Physics of Neutrinos

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Conclusions from the Neutrino Factory and Beta Beam Working Group within the recent APS sponsored Neutrino Physics Study are summarized.

1. Introduction

Beginning in the Fall of 2003, the APS Divisions of Particles and Fields and of Nuclear Physics, together with the Divisions of Astrophysics and the Physics of Beams, sponsored a "year long" Study on the Physics of Neutrinos. The study was intended to lay the scientific groundwork for the neutrino physics choices that must be made during the next few years. One of the working groups within the study was devoted to Neutrino Factories and Beta Beams. This group looked at both the physics motivation, design, and R&D status for these new facilities. The group met at the "kick-off" workshop at ANL in the Fall of 2003, and again at a dedicated meeting at ANL in March 2004. Conclusions from the working group were presented at the concluding APS Study meeting at Snowmass in June 2004. The following summarizes the working group report [1].

2. Working Group Summary

Two new types of facility have been proposed that could have a tremendous impact on future neutrino experiments—the Neutrino Factory [2] and the Beta Beam facility [3]. In contrast to "Superbeams" (conventional muon-neutrino beams from a pion decay channel produced with a MW-scale proton source), Neutrino Factory and Beta Beam facilities would provide a source of electron-neutrinos (ν_e) and -antineutrinos ($\bar{\nu}_e$), with very low systematic uncertainties on the associated beam fluxes and spectra. The experimental signature for $\nu_e \to \nu_\mu$ transitions is extremely clean, with very low background rates. Hence, Neutrino Factories and Beta Beams would enable very sensitive oscillation measurements to be made. This is particularly true at a Neutrino Factory which not only provides very intense beams at high energy, but also provides muon-neutrinos (ν_μ) and -antineutrinos ($\bar{\nu}_\mu$) in addition to electron-neutrinos (ν_e) and -antineutrinos ($\bar{\nu}_e$). This would facilitate a large variety of complementary oscillation measurements in a single detector, and dramatically improve our ability to test the three-flavor mixing framework, measure *CP* violation in the lepton sector, determine the neutrino mass hierarchy and, if necessary, probe extremely small values of the mixing angle θ_{13}. Note that at this time, we do not know the value of θ_{13}. If $\sin^2 2\theta_{13} < 0.01$, much of the basic neutrino oscillation physics program will be beyond the reach of conventional neutrino beams. In this case Neutrino Factories and Beta Beams offer the only known way to pursue the desired physics program.

The sensitivity that could be achieved at a Beta Beam facility presently looks promising, but is still being explored. In particular, the optimum Beta Beam energy is under discussion. Low energy Beta Beam measurements would com-

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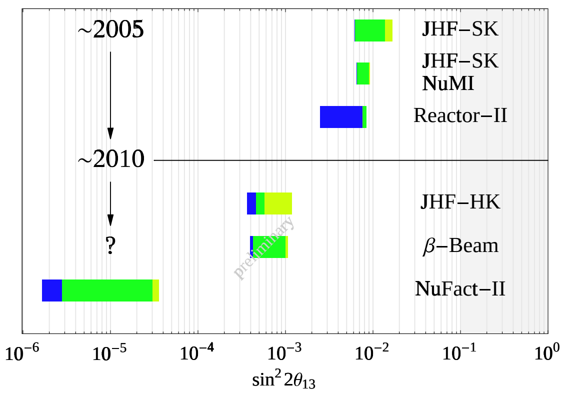

Figure 1. Sensitivity to a non-zero $\sin^2 2\theta_{13}$. The shaded regions within the bars show the degradation of the sensitivities due to irreducible experimental systematics, the effects of correlations, and the effects of false solutions in the three-flavor mixing parameter space. The rightmost limit of the bars therefore gives the expected sensitivities for each experiment. Figure from Ref. [4].

plement Superbeam measurements, but would achieve a θ_{13} sensitivity that does not appear to be competitive with that of a Neutrino Factory (Fig. 1). Higher energy Beta Beams may approach the sensitivity possible with a Neutrino Factory, although systematics issues need further study. In the U.S. context, the only existing accelerator that might be of interest for Beta Beams appears to be the Fermilab Tevatron, which could in principal provide sufficient acceleration to yield heavy ions in an interesting energy range, and accelerate fast compared to the radiaoactive ion lifetime. However, there appears to be a substantial R&D effort that would be required before a Beta Beam could be built. Thus, while a Beta Beam facility may have a significant role to play in the future global neutrino program, more work must be done on its design, development, cost estimate, and physics sensitivity to validate its potential. We note that, due to very limited resources, there has been no significant activity in the U.S. on Beta Beams. Progress on Beta Beam development being made in Europe should be followed, especially if the higher energy solution continues to look interesting.

An impressive Neutrino Factory R&D effort has been ongoing in the U.S. and elsewhere over the last few years. Two design studies [5], each involving about 1M$ of engineering, have established the feasibility of the Neutrino Factory concept, the achievable performance, and the R&D required before a Neutrino Factory could be built. Since the completion of these studies this R&D has been proceeding, and significant progress has been made towards optimizing the design, developing and testing the required accelerator components, and significantly reducing the cost. The working group used the present APS study to update the Neutrino Factory baseline design with ideas that have emerged over the last couple of years and that promise a reduction in the cost of the facility. Specifically, the magnetic profile for the pion capture section of the complex has been reoptimized, the expensive induction linac muon phase rotation system has been replaced by a cheaper and clever rf system, a new accelerating scheme has been invented that is cheaper and has larger acceptance than the previous system, and the larger acceptance has been exploited by replacing the muon cooling channel with a cheaper and simpler channel. These changes have the added benefit that both muon signs are kept throughout the front end of the Neutrino Factory, potentially doubling its performance. Although a full engineering study is still required, we have preliminary indications that the unloaded cost of a Neutrino Factory facility with the updated design will be substantially less than the estimated cost of our previous design (Table 1).

Neutrino Factory R&D has reached a critical stage in which support is required for two key international experiments (MICE and Targetry) and a third-generation international design study. If this support is forthcoming, a Neutrino Factory could be added to the Neutrino Physics roadmap in about a decade.

3. Working Group Recommendations

Accelerator R&D is an essential part of the ongoing global neutrino program. Limited beam

Table 1
Comparison of the estimated cost of the previous Neutrino Factory baseline design from "Feasibility Study 2" (FS2) with the estimated cost for the updated design (FS2a). The first column shows the total facility cost, and the second column the incremental cost if the Proton Driver and Target Hall already exist for a Neutrino Superbeam.

	ALL	No PD
FS2 ($M)	1832	1538
FS2a/FS2	0.67	0.60

intensity is already constraining the neutrino physics program, and will continue to do so in the future. More intense and new types of neutrino beams would have a big impact on the future neutrino program. Given the present uncertainty about the size of θ_{13} *it is critical to support an ongoing and increased U.S. investment in Neutrino Factory accelerator R&D to maintain this technical option.* A Neutrino Factory cannot be built without continued and increased support for its development. Since R&D on the design of frontier accelerator facilities takes many years, support must be provided *now* to have an impact in about a decade.

A Neutrino Factory would require a MW-scale proton source. We thus encourage the rapid development of a Superbeam-type proton source. The Neutrino Factory and Beta Beam Working Group's specific recommendations are:

- ***We recommend that the ongoing Neutrino Factory R&D in the U.S. be given continued encouragement and financial support.*** We note that the HEPAP Report of 2001 recommended an annual support level of $8M for Neutrino Factory R&D, and this level was considered minimal to keep the R&D effort viable.

In addition, and consistent with the above recommendation,

- ***We recommend that the U.S. funding agencies find a way to support the international Muon Ionization Cooling Experiment (MICE), in collaboration with European and Japanese partners.***

- ***We recommend that support be found to ensure that the international Targetry R&D experiment proceeds as planned.***

- ***We recommend that a World Design Study, aimed at solidly establishing the cost of a cost-effective Neutrino Factory, be supported at the same level as Studies I and II.***

Finally,

- ***We recommend that progress on Beta Beam development be monitored, and that our U.S. colleagues cooperate fully with their EU counterparts in assessing how U.S. facilities might play a role in such a program.***

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